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## **Tracking the Exchange Rate Management in Latin America**

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# *Tracking the Exchange Rate Management in Latin America*

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## **Abstract:**

The exchange rate is one of the most important prices in any open economy. Tracking deviations from its long-run value may provide important information for policymakers. One way to track such deviations is to compute the distribution of exchange-rate observed values and compare them with those of Benford's law. I document such cases for 15 Latin American countries, for the two most widely traded currencies. Latin American countries are small open economies that are characterized for having different degrees of dollarization and intervention in the forex market. This is an alternative view of how these characteristics play a role with respect to an implied equilibrium exchange rate.

**JEL Classification: C16, F31, F41**

**Key words: Exchange rate, Forex, Benford's law.**

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# 1. INTRODUCTION

The exchange rate is a key variable for any open economy because it reflects trading and financial conditions. The value of exports and imports is subject to the volatility of the exchange rate. The variability of the exchange rate is also important for the determination of interest rate parity conditions. In that regard, several open economies suffered crises related to the value of the dollar. Accepting payment for debt in dollars when revenues and incomes are in local currency may cause solvency issues if the volatility of the exchange rate is high. In particular, several Latin American economies experience a phenomenon called dollarization (common use of the dollar rather than domestic currency for transactions). In addition, some economies fully replaced their domestic currency and now use U.S. dollars instead.

The forex (FX) market is the world's largest and most liquid market, with trillions of dollars being traded on any given day between millions of parties all around the world. The 2010 Triennial Central Bank Survey, which is conducted by the Bank of International Settlement (BIS), shows a substantial increase in global foreign exchange market activity.<sup>1</sup> According to this survey, the U.S. dollar and the euro are the most widely traded currencies in the world, especially for spot transactions (see Table 1).

On the other hand, Benford's law (the law of the first digit or the law of the leading digits) refers to the frequency distribution of digits in many sources of data. Under this law, the larger the digit the less frequent this digit is likely to be the first digit. The implied distribution of first digits can be described on a logarithmic weakly monotonic distribution.

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<sup>1</sup> Triennial Central Bank Survey: Report on global foreign exchange market activity in 2010. Bank of International Settlements (BIS).

Benford's law can also be extended for the expected distribution for the second digit and beyond. For this law to hold, data have to be distributed across multiple orders of magnitude (for example, the list of numbers that represents the populations of U.S. cities). This law does not hold if there is any cutoff that excludes a portion of the underlying data above a maximum or below a minimum value (for example, cities defined as a settlement with a population between 30,000 and 99,000).

**TABLE 1 – TURNOVER IN THE GLOBAL FOREIGN EXCHANGE MARKETS**

	1998	2001	2004	2007	2010
A. Global foreign exchange market turnover 1/					
Foreign exchange instruments	1527	1239	1934	3324	3981
Spot transactions	568	386	631	1005	1490
Other options and products	959	853	1303	2319	2491
B. Currency distribution of global foreign exchange market turnover 2/					
U.S. dollar	87	90	88	86	85
Euro		38	37	37	39
Other currencies	113	72	75	77	76

NOTES: 1/ DAILY AVERAGES IN APRIL, IN BILLIONS OF U.S. DOLLARS. 2/ PERCENTAGE SHARES OF AVERAGE DAILY TURNOVER IN APRIL (THE SUM OF THE PERCENTAGE SHARES OF INDIVIDUAL CURRENCIES TOTALS 200% INSTEAD OF 100% BECAUSE TWO CURRENCIES ARE INVOLVED IN EACH TRANSACTION). SOURCE: BIS (2010).

The result of Benford's law has been found to apply to a wide variety of data sets, including those of the social sciences. For example, Varian (1972), De Grauwe and Decupere (1992), El Sehity et al. (2005), and Abrantes-Metz et al. (2011) have all used this law to check the validity of supported data in economics.

De Grauwe and Decupere (1992) are the only ones who use Benford's law as a benchmark for realizations of the exchange rate. Donaldson and Kim (1993), Koedijk and Stork (1994), and Ley and Varian (1994) demonstrate the existence of price clustering in the last digit of stock market indices. They also tested for psychological barriers through the observation of unequal passing values of predetermined digits. De Grauwe and Decupere (1992) follow this strategy of clustering in the FX market for the USD/DEM and USD/JPY exchange rates and compare them against the implied distribution in Benford's law. These

studies infer that clustering, or unequal observations of various digits, implies that psychological barriers exist.<sup>2</sup>

In the case of Latin American countries, the application of exchange rate policies is heterogeneous. In the presence of a crisis, policymakers reacted with measures that range from exchange rate bands to open market operations. In that regard, I depart from De Grauwe and Decupere (1992) and argue that the implied Benford's law distribution can be used as a benchmark of long-run misalignments that those policies generate. Rather than using Abrantes-Metz and coauthors' (2011) strategy of a stable period as a benchmark, I use the euro exchange rate as a benchmark for the U.S. dollar exchange rate.

In this paper, I investigate whether deviations in the exchange rate from the implied distribution in Benford's law provides evidence of deviations in the exchange rate from a long-run equilibrium perspective. In that regard, I use samples from at least 10 years over the two most traded currencies in the world for 15 Latin American countries in order to be consistent with a long-run perspective. I basically find that in economies in which exchange rate policies are more active, deviations from Benford's law are stronger. This may suggest that these policies tend to distort this relative price.

The remainder of this paper is organized as follows: Part 2 introduces Benford's law and its relationship with data in economics. Part 3 presents the main characteristic of the data. Part 4 includes an estimation and comparison of each exchange rate distribution versus the implied Benford's distribution. Part 5 concludes.

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<sup>2</sup> Mitchell and Izan (2006) argue that this interpretation is misleading and the evidence found in previous literature is not strong enough to argue in favour of psychological barriers in the exchange rate market.

## 2. BENFORD'S LAW

In a given data set, Benford (1938) shows that the probability of occurrence of a certain digit as the first digit decreases logarithmically as the value of the digit increases from 1 to 9. This observation is known as Benford's law and holds for data sets in which the occurrence of numbers is free from any restriction. This result has been probed to hold for a wide variety of variables.<sup>3</sup> This law can be generalized to numbers with a base different than 10, or to posterior positions of a digit in a number.<sup>4</sup>

Several studies show that numbers that have been tampered with or are unrelated or fabricated do not usually follow Benford's law. Thus, significant deviations from the Benford implied distribution may indicate unauthorized intervention or fraudulent or corrupted data.

### 2.1 The first and second digit

Benford's law implies that the probability of a digit to be the first digit in a numerical variable is given by:

$$Prob(x = d) = \log_{10}(1 + d^{-1}) \text{ for } d = 1, 2, 3, \dots, 9 \quad (1)$$

where  $d$  is the value of the digit.

Equation (1) can be generalized for the probability of being the second digit:

$$Prob(x = d) = \sum_{k=1}^9 \log_{10}[1 + (10k + d)^{-1}] \text{ for } d = 0, 1, 2, 3, \dots, 9 \quad (2)$$

Equations (1) and (2) imply distributions for the first and second digit of a numerical variable, respectively (see Table 2 and Figure 1).

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<sup>3</sup> In Benford (1938), the data from 20 different domains are tested. The original data set included the surface areas of 335 rivers, the sizes of 3,259 U.S. populations, 104 physical constants, 1,800 molecular weights, 5,000 entries from a mathematical handbook, 308 numbers contained in an issue of *Readers' Digest*, the street addresses of the first 342 persons listed in *American Men of Science*, and 418 death rates.

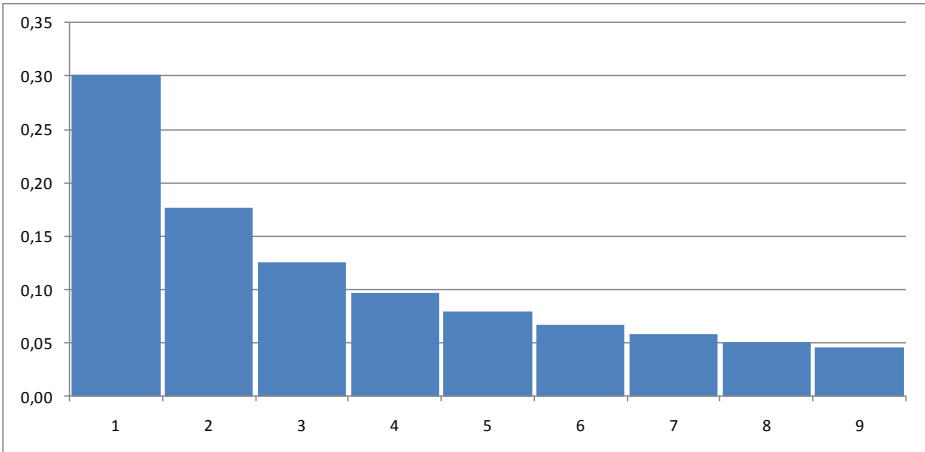
<sup>4</sup> For details and extensions to Benford's law, see Gottwald and Nicol (2002), Lolbert (2008), and Clippe and Ausloos (2012).

**TABLE 2 – BENFORD’S LAW**

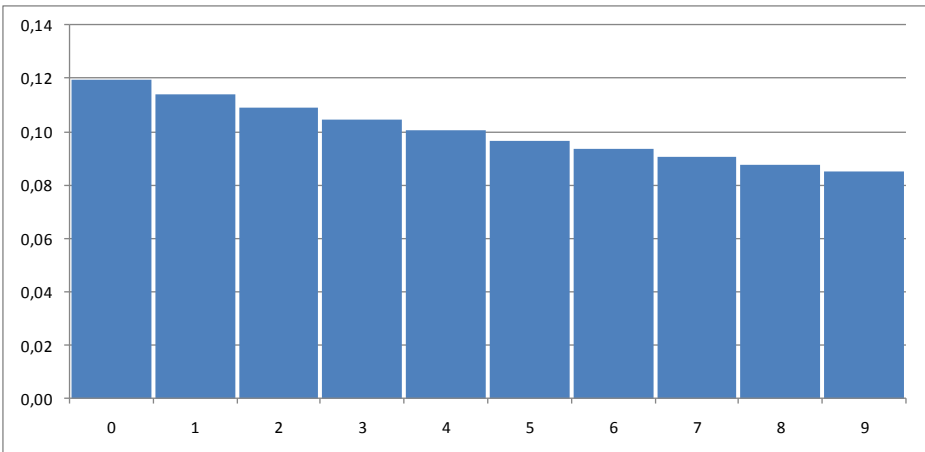
<u>Digit</u>	<u>First digit</u>	<u>Second digit</u>
0		0,12
1	0,30	0,11
2	0,18	0,11
3	0,12	0,10
4	0,10	0,10
5	0,08	0,10
6	0,07	0,09
7	0,06	0,09
8	0,05	0,09
9	0,05	0,08

**FIGURE 1 – BENFORD’S LAW**

**A: FIRST DIGIT**



**B: SECOND DIGIT**



## 2.2 Use of Benford's law in Economics

Varian (1972) argues that Benford's law could be used to detect possible fraud in socio-economic data. If people who make up figures tend to distribute their digits uniformly, then comparing the frequency of the first-digit distribution with that expected from Benford's distribution would show significant differences. Along the same lines, Nigrini (1999) showed that Benford's law could be used in auditing as an indicator of accounting and expenses fraud.

El Sehity et al. (2005) use Benford's law as a benchmark for price adjustments and for detecting irregularities in prices. El Sehity et al. (2005) use two facts: (i) retail managers use psychological pricing to make the prices of goods appear to be just below a round number, and (ii) the euro was introduced in several cities in 2002. Those facts distorted existing nominal price patterns while at the same time retaining real prices. The authors find that the tendency toward psychological prices results in different inflation rates independent of the price pattern.

Some other works that use Benford's law and the idea of a psychological barrier in financial assets are De Grauwe and Decupere (1992), De Ceuster et al. (1998), Aggarwal and Lucey (2007), and Dorfleitner and Klein (2009). In particular, De Grauwe and Decupere (1992) cluster the USD/DEM and USD/JPY exchange rates and compare them against Benford's law. De Grauwe and Decupere (1992), Ley (1996), and De Ceuster et al. (1998) argue that Benford's law describes many data series, including financial data, so that widespread clustering simply due to the form of the number itself is possible.

Abrantes-Metz and Bajari (2009) study how statistical methods have started to be used in antitrust and finance to detect a variety of conspiracies and manipulations. Abrantes-Metz et al. (2011) investigate deviations of the LIBOR from equilibrium values by testing different



realizations for different samples (around February 2006) and suggest that those deviations have as a source the collusion among big commercial banks.

### *2.3 Equilibrium exchange rate?*

The real exchange rate equilibrium value has always been a key issue in international economics. Views about its behavior range from the short-run market approach to the long-run power purchasing parity theory. Among all views to derive equilibrium exchange rate values, the Behavioral Equilibrium Exchange Rate (BEER) approach is one of the most accepted and is based on a long-run (cointegrating) relationship between the real exchange rate and economic fundamentals. The BEER value is the predicted exchange rate from the cointegrating equation. This long-run view is complemented with a vector error correction model (VECM) that identifies how quickly the real exchange rate converges toward its long-run equilibrium value.

Dufrénot et al., (2008) argue that the experience of real exchange rates has been characterized by substantial misalignments, with time lengths much higher than those suggested by theoretical models. According to the standard view, deviations from the equilibrium level are temporal because there are forces that ensure mean-reverting dynamics. Béreau et al. (2010) points out that this relationship can be explained with nonlinear dynamics and, if so, that exchange rates can spend long periods away from their fundamental values.

The goal of my paper is to contribute to this literature by providing evidence of such misalignments process of the exchange rate toward its equilibrium value.

### 3. DATA CHARACTERISTICS

Previous to testing the deviations of the exchange rate from equilibrium values, I describe first the currencies under inspection and then describe the two exchange rates. In the next section, I use these results to test the deviations from the distribution implied by Equation (2).

In this paper, “exchange rate” refers to the spot exchange rate.<sup>5</sup> For most countries in this sample, this variable is also known as the interbank exchange rate. The data are taken from Bloomberg and at daily frequency. For most countries, the data for the U.S. dollar exchange rate became available beginning in 1993. Some other countries have data available starting in 1994. Data for the euro exchange rate begin in 1999.

#### *3.1 Latin American currencies*

In Latin American countries, exchange rate policies refer to the U.S. dollar. For most Latin American countries during the 1990s, the exchange rate policy was characterized by an exchange rate target zone that takes the form of a band, i.e., the exchange rate was flexible as long as it was inside the limits of the band. During the 2000s, a float managed exchange rate was used. Interventions in the exchange rate market to either influence the exchange rate inside the band or reduce its volatility have been the common factor in the region.

The northern countries of South America, such as Colombia and Venezuela, followed fairly different approaches with respect to the exchange rate. In Colombia, during the 90s, the exchange rate policy was characterized for exchange-rate bands (in some periods with even a crawling peg in the limit of the band). During the 2000s, the mechanism was direct

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<sup>5</sup> This is the rate of a foreign exchange contract for immediate delivery. Spot exchange rates are also known as “benchmark rates” because spot rates represent the price that a buyer expects to pay for a foreign currency in another currency.

intervention. In Venezuela, the exchange rate policy can be characterized as exchange rate bands (90s) and a fixed exchange rate, which is under review every year (2000s).

Some other countries such as Brazil and Argentina experienced major changes in their domestic currencies in the 90s. These countries were looking for pegged exchange rates at equal parity to the U.S. dollar. By the 2000s, they both follow managed float exchange rate policies.<sup>6</sup> Neighboring countries such as Uruguay and Paraguay followed different exchange rate policies. Uruguay was directly affected by the exchange rate policy in Argentina, and during the 90s, this country used an exchange rate band, turning to a managed float exchange rate in the 2000s.

In the Pacific, there were also mixed policies. While Chile used a band during the 90s and then switched to a managed float exchange rate, Peru primarily used a managed float exchange rate in which interventions were aimed at the reduction in the volatility of the exchange rate. On the other hand, Ecuador used direct interventions, with a central bank fixing the exchange rate. In 1994, the country had a managed float exchange rate; in 1995, it used exchange rate bands; and it began using a full dollarization program in 2000.<sup>7</sup>

In Central America, there were also mixed exchange rate policies. In Guatemala and the Dominican Republic, the exchange rate was fixed (crawling peg) by the government (in the 90s) and a managed float policy was instituted thereafter (2000s). Costa Rica adopted the crawling-peg policy (in the 90s and the mid-2000s) and then crawling bands. El Salvador used a fixed exchange rate (during the 90s) and, since January 2001, the U.S. dollar has become that country's legal tender.<sup>8</sup>

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<sup>6</sup> In the case of Argentina, from January 1992 to January 2002 (this period is known as Plan de Convertibilidad), 1 peso equaled 1 U.S. dollar. Since then it has been allowed to float freely. The official Brazilian rate, from October 1993 to January 1999 (plan Real), was 1 real equals 1 U.S. dollar. Since January 1999, the official rate has been the managed float exchange rate.

<sup>7</sup> On March 13, 2000, the Ecuadorian National Congress approved a new exchange system whereby the U.S. dollar was adopted as the main legal tender in Ecuador for all purposes; on March 20, 2000, the Central Bank of Ecuador started to exchange sucres for U.S. dollars at a fixed rate of 25,000 sucres per U.S. dollar; and since April 30, 2000, all transactions have been denominated in U.S. dollars.

<sup>8</sup> The exchange rate was then fixed at 8.75 colones per U.S. dollar. Since 1993, the rate has been fixed at 8.755.

At the beginning of the 1990s, Mexico used a band policy, with a fixed lower bound and a crawling peg in the upper bound. Later on (in 1994) the band scheme was abandoned, and Mexico entered into a scheme of a managed float exchange rate.

### *3.2 The U.S. dollar and the euro*

The first and foremost traded currency in the world is the U.S. dollar. This currency can be found in a pair with any currency and often acts as the intermediary in triangular currency transactions. In addition, the U.S. dollar is used by some countries as the official currency (dollarization) and is widely accepted in other nations, acting as an alternative form of payment (partial dollarization). The U.S. dollar is also a benchmark or target rate for countries that choose to fix or peg their currencies in order to stabilize their exchange rates.

The euro was introduced into world markets on January 1, 1999, and it is the official currency of the majority of nations within the eurozone. Despite being a new currency, the euro has quickly become the second most traded currency and the world's second largest reserve currency. As a matter of fact, many nations within Europe and Africa peg their currencies to the euro to stabilize their exchange rates. With the euro being a widely used and trusted currency, it is very prevalent in the FX market and adds liquidity to any currency pair it trades within.

## **4. ESTIMATIONS AND EMPIRICS**

The distribution implied in Benford's law can be thought of as a benchmark that permits identification of the deviation in the realization of a variable from equilibrium values. In the absence of any intervention, the exchange rate should reflect fundamental conditions.

Realizations of the exchange rate in the long run would follow Benford's law. That is why Equation (2) is a reasonably good measure of the deviations from the implied equilibrium in Benford's law.

The use of at least 10 years of such realizations is justified by the need of taking off the autocorrelation implied in financial variables. As Aggarwal and Lucey (2007) argue, in a short period of time, uniformity of digit distribution is expected and that runs counter to the implications of Benford's law. As Abramantes-Metz (2011) argues, if the variable of interest does not span the nine-digit space, the second-digit data may be expected to naturally do so. Therefore, if the sample is long enough, the study of the second digit would have more meaningful results.

#### *4.1 Benford's law and the exchange rate distribution*

I now turn to the main question, which is whether the realization of the interbank exchange rate data can be reasonably well represented by the Benford's second-digit reference distribution implied by Equation (2). In that regard, the Pearson's chi-square test can be used to evaluate if the statistical distribution of a random sample is drawn from Benford's law.

For Equation (2), the corresponding  $\chi^2$  statistic can be estimated as:

$$\chi_{stat}^2 = \sum_{i=0}^9 \frac{(e_i - b_i)^2}{b_i} \quad (3)$$

where  $e_i$  is the observed frequency in each bin in the observed data and  $b_i$  is the expected frequency implied by Benford's law.<sup>9</sup>

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<sup>9</sup> This statistic has 9 degrees of freedom.

The null and the alternative hypotheses to test are:

$H_0$ : Data are drawn from Benford's distribution.

$H_A$ : Data are not drawn from Benford's distribution.

If the observed data fit Benford's law,  $\chi_{stat}^2$  has to be less than the critical value at the convenient statistical significance level, i.e., fail to reject  $H_0$ . If  $\chi_{stat}^2$  is greater than the critical value, reject  $H_0$ .

It is fair to say that  $\chi_{stat}^2$  works as a measure of a gap in between the realization observed in the data and that implied in Benford's distribution. The larger  $\chi_{stat}^2$  is, the stronger the deviation from the implied distribution is.

In Table 3, I show that most currencies tend to deviate from Benford's law's implied distribution. Argentina and Venezuela, countries that experienced strong exchange rate policies, have the largest  $\chi_{stat}^2$ . On the other hand, Chile and Ecuador register the lowest  $\chi_{stat}^2$ . This may indicate the lower intervention in the exchange rate market of Chile and the low effectiveness of the exchange rate policy in Ecuador.

**TABLE 3 – SOUTH AMERICAN COUNTRIES**

Digit	Argentina 1992-2012	Bolivia 1993-2012	Brazil 1992-2012	Chile 1992-2012	Colombia 1992-2012	Ecuador 1993-2000	Paraguay 1993-2012	Peru 1992-2012	Uruguay 1993-2012	Venezuela 1998-2012
0	0,36	0,29	0,22	0,12	0,13	0,11	0,12	0,05	0,13	0,00
1	0,07	0,04	0,13	0,18	0,08	0,17	0,11	0,11	0,12	0,35
2	0,02	0,04	0,05	0,11	0,13	0,14	0,08	0,14	0,08	0,22
3	0,02	0,03	0,05	0,10	0,15	0,10	0,09	0,09	0,16	0,02
4	0,02	0,05	0,03	0,07	0,04	0,08	0,08	0,21	0,12	0,01
5	0,02	0,08	0,04	0,05	0,06	0,09	0,09	0,09	0,04	0,10
6	0,02	0,08	0,07	0,09	0,05	0,06	0,06	0,10	0,05	0,12
7	0,03	0,07	0,13	0,10	0,11	0,06	0,11	0,08	0,06	0,08
8	0,08	0,06	0,15	0,09	0,13	0,08	0,11	0,09	0,07	0,01
9	0,35	0,27	0,14	0,08	0,13	0,11	0,15	0,06	0,16	0,09
$\chi^2$ - stat	163,55	83,66	33,29	6,28	17,05	6,92	9,05	17,70	17,76	92,19
$p$ - value	0,00	0,00	0,00	0,71	0,05	0,65	0,43	0,04	0,04	0,00

Table 4 presents results for other Latin American countries. All of them deviate from Benford's law. As expected, the crawling-peg exchange rate policy followed in most of these countries affected the observed distribution of the spot exchange rate.

**TABLE 4 – OTHER LATIN AMERICAN COUNTRIES**

Digit	Costa Rica 1994-2012	Dominican Rep. 1993-2012	El Salvador 1993-2012	Guatemala 1993-2012	Mexico 1992-2012
0	0,17	0,02	0,00	0,09	0,25
1	0,19	0,02	0,00	0,05	0,22
2	0,08	0,10	0,00	0,05	0,13
3	0,06	0,13	0,00	0,05	0,14
4	0,05	0,09	0,00	0,02	0,07
5	0,08	0,17	0,00	0,08	0,05
6	0,06	0,20	0,02	0,19	0,03
7	0,07	0,13	0,98	0,19	0,03
8	0,09	0,08	0,00	0,17	0,04
9	0,14	0,07	0,00	0,13	0,04
$\chi^2$ - stat	17,37	34,96	957,48	48,16	42,91
$p$ - value	0,04	0,00	0,00	0,00	0,00

#### 4.2 The euro: A Benchmark

A natural extension of this analysis is to make homogeneous samples for all countries. First of all, I estimate the exchange rate against the U.S. dollar for the period from 1994 through 2012. Then, I calculate a similar distribution for the euro spot exchange rate. Given the fact that the euro appeared in 1999, I re-estimate the distribution of the U.S. exchange rate for the sample period. Finally, I re-estimate the distribution of the U.S. and the euro exchange rate for sample periods at least 10 years longer.

Table 5 presents the outcome from the homogeneous sample period for all countries. In the case of the U.S. dollar for 1994 to 2012, the results slightly differ from the whole sample analysis. There are no surprises here. When the euro exchange rate is considered, Benford's law holds for most countries. This fact may have support from the little intervention in the euro exchange rate market. In order to make a reasonable comparison between these two currencies, I consider a similar sample for the U.S. exchange rate. Only Chile and Paraguay have exchange rate distributions in line with the distribution suggested by Benford's law.

**TABLE 5 – EXCHANGE RATE AND BENFORD’S LAW**

	U.S. Dollar (1994-2012)		Euro (1999-2012)		U.S. Dollar (1999-2012)	
	$\chi^2$ - stat	p - value	$\chi^2$ - stat	p - value	$\chi^2$ - stat	p - value
Argentina	140,26	0,00	13,86	0,13	103,11	0,00
Bolivia	85,80	0,00	38,84	0,00	112,34	0,00
Brazil	29,09	0,00	22,16	0,01	29,11	0,00
Chile	8,07	0,53	2,99	0,96	4,92	0,84
Colombia	19,23	0,02	13,16	0,16	36,38	0,00
Paraguay	8,88	0,45	5,18	0,82	6,88	0,65
Peru	22,46	0,01	13,49	0,14	35,62	0,00
Uruguay	17,56	0,04	7,89	0,55	29,77	0,00
Venezuela			47,62	0,00	92,33	0,00
Costa Rica	17,37	0,04	8,62	0,47	22,05	0,01
Dominican Republic	35,24	0,00	12,17	0,20	40,03	0,00
El Salvador	960,39	0,00	70,45	0,00	956,83	0,00
Guatemala	47,72	0,00	46,60	0,00	60,60	0,00
Mexico	33,63	0,00	17,23	0,05	73,53	0,00

In the case of the U.S. dollar, there are differences, even if small, when the sample is reduced. The  $\chi_{stat}^2$ , which is my measure of the gap between distributions, suggests that fewer years of observations may distort the original results. Therefore, it is worth it to observe the evolution of the  $\chi_{stat}^2$  in a sample period that has at least 10 years' worth of observations and still stay in the long-run view of the exchange rate.

Table 6 provides the  $\chi_{stat}^2$  for the U.S. exchange rate for samples of 14, 13, 12, 11, and 10 years. From Table 6 it is possible to infer that for most countries, Benford's law does not hold. Some countries have a bigger gap than others, some countries keep experiencing an increasing upward trend, and some countries tend to reduce this gap. At the margin, some countries sort of have a fixed exchange rate, which clearly differs from Benford's law.

On the other hand, Table 7 shows a similar comparison for the euro exchange rate. In this case, Benford's law holds for most countries at different sample sizes. The absence of an explicit exchange rate policy with respect to the euro may explain this result.



**TABLE 6 – U.S. EXCHANGE RATE AND BENFORD’S LAW**

	1999-2012		2000-2012		2001-2012		2002-2012		2003-2012	
	$\chi^2$ - stat	p - value	$\chi^2$ - stat	p - value	$\chi^2$ - stat	p - value	$\chi^2$ - stat	p - value	$\chi^2$ - stat	p - value
Argentina	103,11	0,00	89,98	0,00	67,91	0,00	53,57	0,00	70,25	0,00
Bolivia	112,34	0,00	122,48	0,00	139,96	0,00	175,49	0,00	202,65	0,00
Brazil	29,11	0,00	24,33	0,00	16,10	0,06	20,81	0,01	26,60	0,00
Chile	4,92	0,84	4,33	0,89	4,79	0,85	5,23	0,81	8,29	0,50
Colombia	36,38	0,00	38,77	0,00	46,62	0,00	47,47	0,00	50,87	0,00
Paraguay	6,88	0,65	6,41	0,70	11,07	0,27	14,37	0,11	15,58	0,08
Peru	35,62	0,00	35,17	0,00	25,34	0,00	23,61	0,00	23,78	0,00
Uruguay	29,77	0,00	36,62	0,00	50,53	0,00	53,38	0,00	67,88	0,00
Venezuela	92,33	0,00	106,73	0,00	134,05	0,00	168,59	0,00	212,07	0,00
Costa Rica	22,05	0,01	23,71	0,00	17,50	0,04	27,19	0,00	38,45	0,00
Dominican Republic	40,03	0,00	35,70	0,00	32,88	0,00	26,13	0,00	21,43	0,01
El Salvador	956,83	0,00	992,84	0,00	1006,78	0,00	1006,78	0,00	1006,78	0,00
Guatemala	60,60	0,00	64,92	0,00	58,01	0,00	55,07	0,00	51,63	0,00
Mexico	73,53	0,00	85,12	0,00	103,86	0,00	116,81	0,00	127,21	0,00

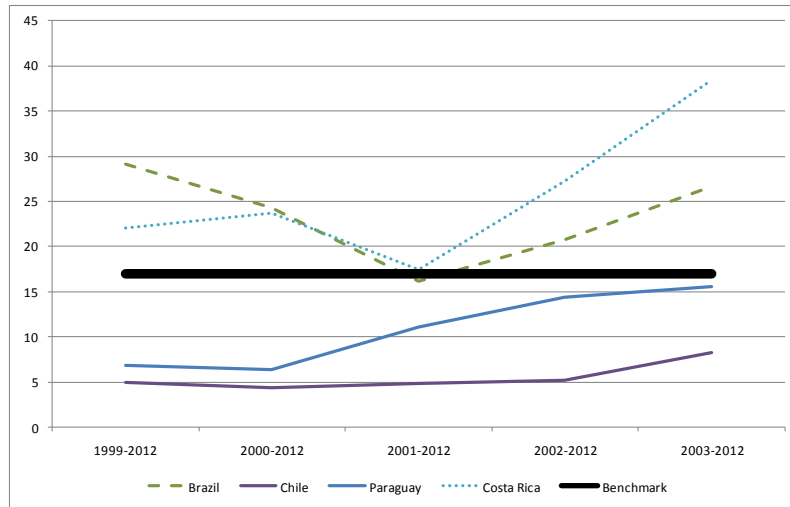
**TABLE 7 – EURO EXCHANGE RATE AND BENFORD’S LAW**

	1999-2012		2000-2012		2001-2012		2002-2012		2003-2012	
	$\chi^2$ - stat	p - value	$\chi^2$ - stat	p - value	$\chi^2$ - stat	p - value	$\chi^2$ - stat	p - value	$\chi^2$ - stat	p - value
Argentina	13,86	0,13	20,53	0,01	14,53	0,10	11,65	0,23	9,95	0,35
Bolivia	38,84	0,00	42,32	0,00	51,41	0,00	54,25	0,00	60,97	0,00
Brazil	22,16	0,01	28,23	0,00	21,65	0,01	30,44	0,00	39,69	0,00
Chile	2,99	0,96	4,42	0,88	3,04	0,96	4,08	0,91	3,10	0,96
Colombia	13,16	0,16	12,83	0,17	7,43	0,59	6,99	0,64	7,08	0,63
Paraguay	5,18	0,82	5,81	0,76	5,24	0,81	5,72	0,77	6,41	0,70
Peru	13,49	0,14	20,32	0,02	18,53	0,03	15,01	0,09	20,97	0,01
Uruguay	7,89	0,55	8,56	0,48	9,08	0,43	14,73	0,10	12,16	0,20
Venezuela	47,62	0,00	33,02	0,00	22,53	0,01	17,29	0,04	18,33	0,03
Costa Rica	8,62	0,47	5,11	0,82	2,95	0,97	1,56	1,00	0,98	1,00
Dominican Republic	12,17	0,20	12,17	0,20	8,20	0,51	4,69	0,86	6,17	0,72
El Salvador	70,45	0,00	79,86	0,00	98,53	0,00	121,22	0,00	159,00	0,00
Guatemala	46,60	0,00	56,07	0,00	66,77	0,00	76,66	0,00	93,77	0,00
Mexico	17,23	0,05	23,15	0,01	27,65	0,00	34,14	0,00	45,77	0,00

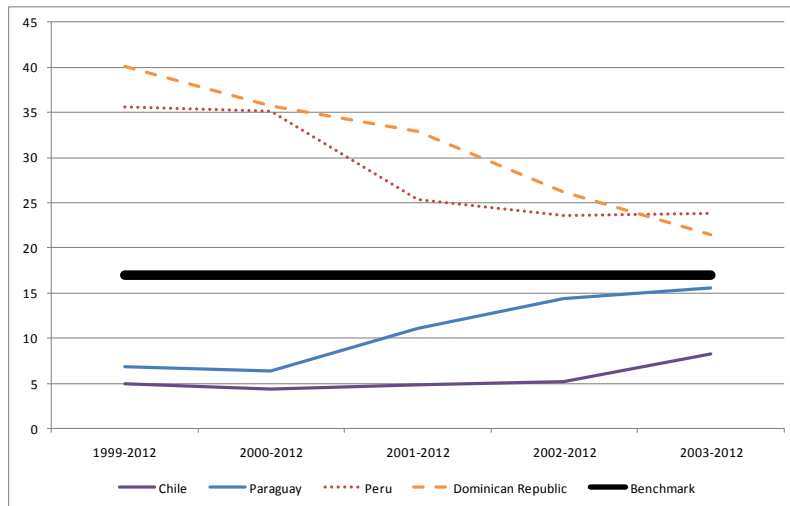
In Figure 2, I present the behavior of the  $\chi^2_{Stat}$  for the case of the U.S. dollar. There are a couple of countries well inside the region of Benford’s law (Chile and Paraguay); there are a couple more that have a clear tendency to reach this threshold (Dominican Republic and Peru, Figure 2A); and there are a couple of countries that reach this area and then tend to diverge (Brazil and Costa Rica, Figure 2B).

**FIGURE 2 –  $\chi^2_{stat}$  FOR THE U.S. DOLLAR**

**A:**



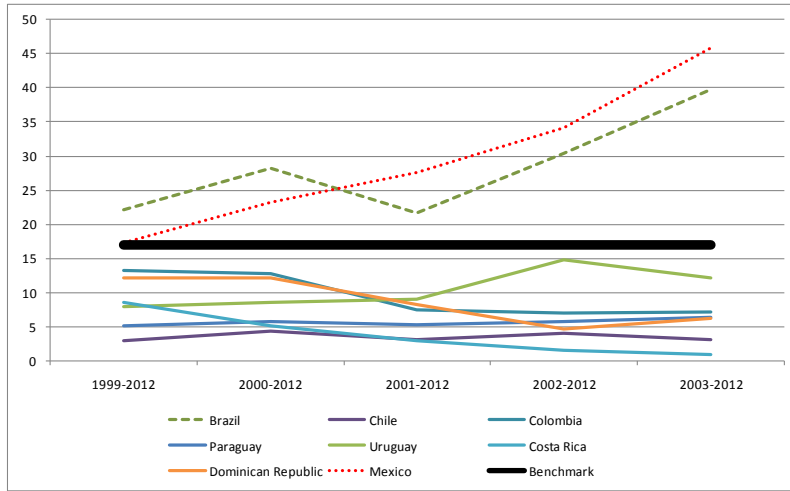
**B:**



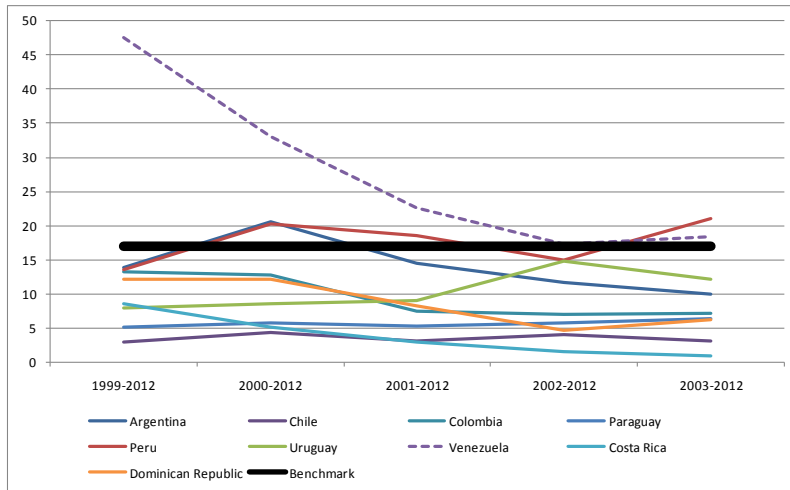
In Figure 3, the  $\chi^2_{stat}$  for the case of the euro is clearly inside the threshold of Benford's law. In the cases of Mexico and Brazil, the gap tends to increase as the sample considers a fewer number of years (Figure 3A). Surprisingly, as the sample is reduced, Benford's law tends to hold for Venezuela (Figure 3B).

**FIGURE 3 –  $\chi^2_{stat}$  FOR THE EURO**

**A:**



**B:**



#### 4.3 Deviations from Benford reference distribution

Numerous factors may explain temporal misalignments: transaction costs, heterogeneity of buyers and sellers, speculative attacks on currencies, the presence of target zones, noisy traders causing abrupt changes, and the heterogeneity of central banks' interventions. All these factors imply either a relationship between the exchange rate and the economic fundamentals or an adjustment mechanism with time-dependent properties.

Here, I consider a period long enough that the adjustment process can be viewed as a short-run deviation from the fundamentals of the economy. The detected processes here help at modeling asymmetries inherent to the adjustment process. This is particularly interesting because these asymmetries may explain, for instance, the unequal durations of undervaluations and overvaluations. Here, all I can say is that there are deviations from a long-run equilibrium exchange rate perspective, and these deviations seem to be stronger in some cases, even though a flexible exchange regime is in place.

## **5. CONCLUSIONS**

I use Benford's law to compare the realization of the exchange rate with respect to long-run implied equilibrium realizations of the U.S. dollar exchange rate. Benford's implied distribution can be viewed as a reasonable alternative to structural models of the fundamental exchange rate to detect deviations from a long-run perspective. Deviations from this implied distribution may be reflecting factors such as transaction costs, changing regimes fluctuations, or open market operations. Moreover, such an approach helps to understand delays that are inherent to the adjustment process. This is particularly interesting because these delays may explain the unequal likelihood of undervaluations or overvaluations. As a second step, I make a comparison against a currency that has a less active monetary policy: the euro.

In the case of the U.S. dollar, Benford's law holds for two countries (Chile and Paraguay); however, in the case of the euro, the law seems to hold for most Latin American countries. Although the U.S. dollar is important for most transactions in these economies and there are explicit policies associated with it, the euro has become an important currency and

an alternative to the U.S. dollar in these countries as well, even though there are not active policies regarding the exchange rate observed in the market.

Finally, I find that the gap for this law to hold true became lower in the U.S. dollar exchange rate market for the case of Dominican Republic and Peru, which suggests that if the exchange rate is deviated, this deviation seems not to hold under a long-run perspective.

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